Complementary Nucleon Pick-up and Stripping Experiments and New Data on Nuclear Subshells

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Abstract. Due to significant systematical errors of the experimental nuclear spectroscopy data obtained by different methods one is often forced to deal with a very discrepant data. To remove the systematical errors and increase data accuracy and reliability, new data processing technologies were developed. One can obtain also new information have not (could not) been obtained before. It is shown that energies of the first 2^+ levels in Zr isotopes can be explained in the framework of the shell-model approach. A separation of $2d_{5/2}$ subshell in ^{96}Zr (like $1f_{7/2}$ subshell in ^{48}Ca) is found, so the neutron number N = 56 becomes like a magic number for Z = 40. To explain a similarity in decay properties of ^{48}Ca and ^{96}Zr an additional interaction between closed structures consisting of 20 and 28 nucleons is proposed. Irregularities of the ground state spin values in K isotopes are explained by the inversion of the proton $1d_{3/2}$ and $2s_{1/2}$ orbitals.

INTRODUCTION

The methods of the extracting of the physical information from data of any experiment are based usually on using of relationships of a definite degree of generalization. If it is possible to connect data of two or more experiments using more general relations than those used for data extracting from experiments it means that one has a group of complementary experiments. Connecting each other of the complementary experimental data via more general relations can help to overcome information limitation of typical data obtained in ordinary way: it means a removing a systematical deviations caused by assumed model dependence from data analyzed jointly.

The nucleon pick-up and stripping reactions experiments on the same initial nucleus present an example of the complementary pair concerns. The values of the spectroscopic factors can be obtained from these experiments by taking into account, as a rule, the DWBA normalization procedure and definite kind of the nuclear potential. As a result, absolute values of the spectroscopic values can differ by factor 2 and more. Besides, ignorance of some *j* values increases the systematical uncertainty significantly. The only exception is experiments with polarized particles. However, if spin and parity of the initial nucleus are equal to 0^+ the total transferred angular momentum is equal to that of a level feeding in the final nucleus.

PUTTING NUCLEON PICK-UP AND STRIPPING REACTION DATA IN ACCORDANCE TO EACH OTHER

The main idea of the method[1)] is to correct the experimental data so that the following constraints:

$$S_{nlj}^{+} + S_{nlj}^{-} = 2j + 1 \qquad (1)$$

should fill out 3 single-particle orbitals closest to Fermi energy, for which data are presented with a maximum of completeness[2)]. Moreover,

$$S_{nlj}^{+} + S_{nlj}^{-} \leq 2j + 1 \qquad (2)$$

for the rest, and

$$\left| \sum_{nlj} S_{nlj}^{-} - \sum_{nlj} S_{nlj}^{+} - N \right| \to 0 \qquad (3)$$

for all. Here $S_{nlj}^{\mp}$ are sums of the individual spectroscopic factors $S_{nlj}^{\mp}(E_x)$ of levels with energies E_x. The upper signs + and – denote a nucleon stripping and pick-up, correspondingly. The sum in (3) is taken over valent and upper subshells in the first term and over the lower subshells in the second one. *N* is a nucleus total number of nucleons (protons or neutrons). The essence of (3) is that a residual interaction does not change the total number of nucleons in a nucleus. To this aim two degrees of freedom are used: (i) a new normalization condition for experimental data is introduced ($S^{+}_{nlj}(E_x) \rightarrow n^{+} S^{+}_{nlj}(E_x)$, $S^{-}_{nlj}(Ex) \rightarrow n^{-} S^{-}_{nlj}(Ex)$); (ii) all known information about a spin of the final states is taken into account, and moreover, all possibilities are investigated for states with unknown spins.

As a result, intervals for factors n^{+} and n^{-} as well as for j values are determined. More reliable values of spectroscopic factors allow one to avoid a discrepancy between various experimental data, both pick-up data and stripping data.

Nucleon occupation probabilities of single-particle orbitals

$$N_{nlj} = \frac{\left[S^{-}_{nlj} + (2j+1-S^{+}_{nlj})\right]}{2(2j+1)} \quad (4)$$

and single-particle energies

$$-E_{nlj} = (1-N_{nlj})\left[B(A+1) - e^{+}_{nlj}\right] + N_{nlj}\left[B(A) + e^{-}_{nlj}\right] \quad (5)$$

are determined by using the improved spectroscopic factors. In (5) $B(A)$, $B(A+1)$ are separation energies of a corresponding nucleon in a target nucleus and in a nucleus with one added nucleon; e^{+}_{nlj}, e^{-}_{nlj} are centroids of the spectroscopic factor distributions.

Databases ENSDF[3,4] and NSR[5] were used as a source of the pick-up, stripping, and spin value data.

EVIDENCE OF THE MAGITY OF ^{96}Zr

Table 1 presents the energies of the first 2^+ states in $^{90,92,94,96}Zr$ isotopes. There are clear maxima at N = 50 and N = 56. The N = 50 maximum has an ordinary explanation, because N = 50 is the well-known magic number. However, the N = 56 maximum demands a special explanation.

TABLE 1. Rounded energies of the first 2^+ states of even-even nuclei of Zr.

Nucleus	^{90}Zr	^{92}Zr	^{94}Zr	^{96}Zr
Number of neutrons N	50	52	54	56
$E(2^+,1)$, keV	2187	935	919	1751

Neutron single-particle energies obtained via the method described above are displayed in Fig. 1. Increasing in N leads to a lowering of the $2d_{5/2}$ subshell from the shell N = 51 - 82 so that in ^{96}Zr the subshell becomes well separated from it. Since in ^{96}Zr the neutron subshell $2d_{5/2}$ is closed, N = 56 becomes somewhat like a magic number (analogous picture of a separation of the subshell $1f_{7/2}$ in Ca isotopes was found out earlier[6)], the neutron number N = 28 was suggested to consider (Fig.2) as a magic one). Correspondingly, two maxima of the energies of the first 2^+ states at the neutron numbers N = 20 and N = 28 one can observe in Ca isotopes (see Table 2).

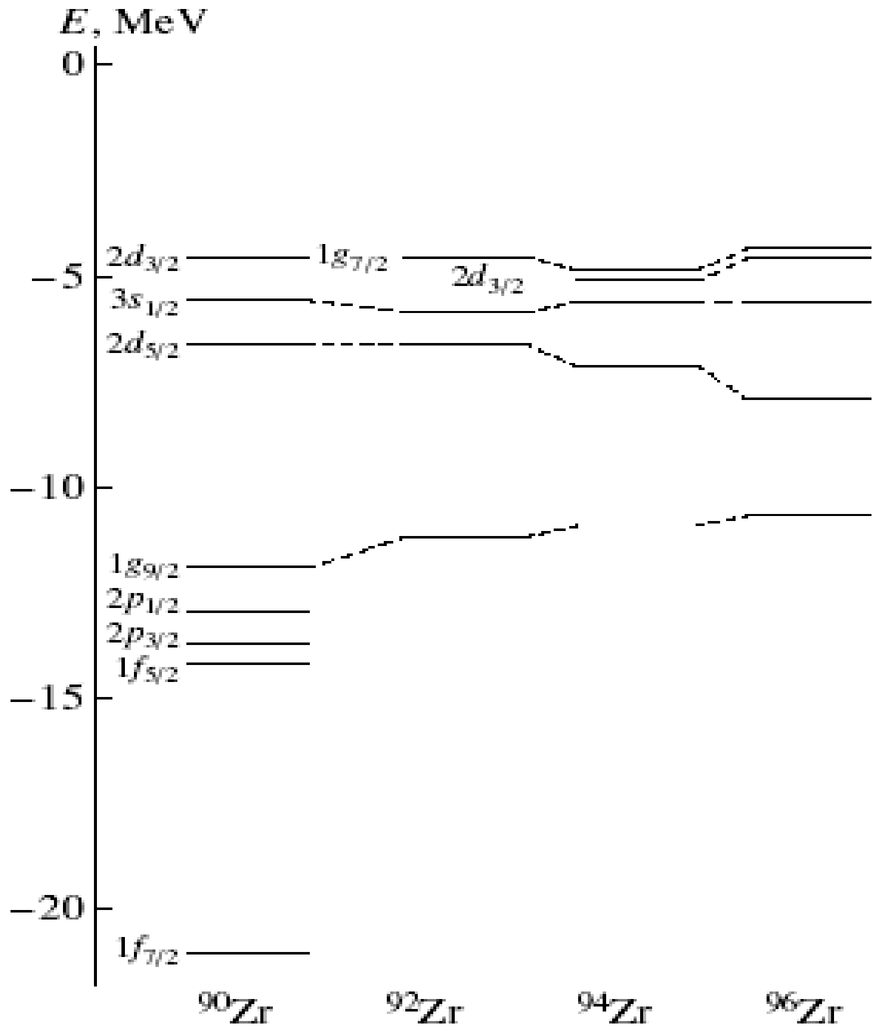


FIGURE 1. Positions of neutron subshells in $^{90.92.94.96}$Zr isotopes.

TABLE 2. Rounded energies E(2^+,1) of the first 2^+ states of even-even nuclei of Ca.					
Nucl	^{40}Ca	^{42}Ca	^{44}Ca	^{46}Ca	^{48}Ca
N	20	22	24	26	28
E, keV	3905	1525	1157	1346	3832

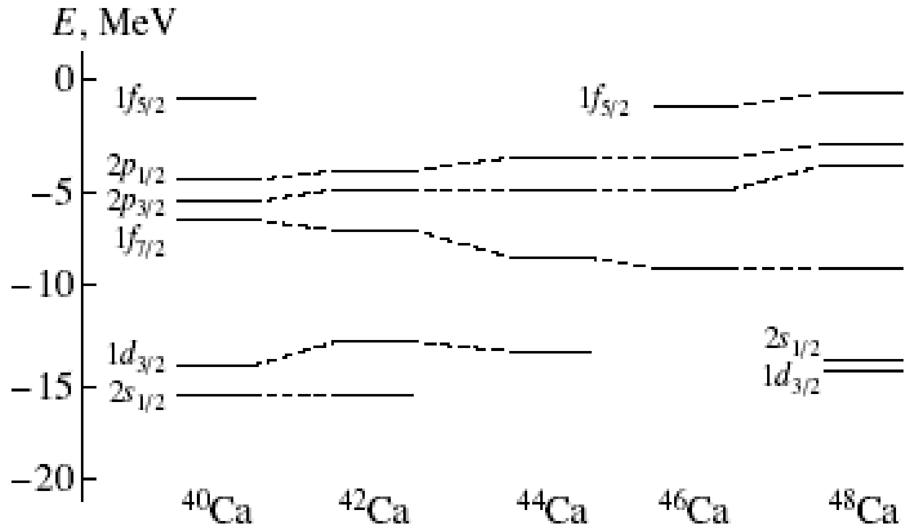


FIGURE 2. Positions of neutron subshells in $^{40.42.44.46.48}$Ca isotopes.

Table 3 presents the results of investigations of proton subshells in Zr isotopes. Whereas the occupation probabilities in ^{90,92,94}Zr are close to 0.1 in the $1g_{9/2}$ orbital (thus corresponding to one proton in this orbital), probability of the proton $1g_{9/2}$ orbital appears to be exactly zero in ^{96}Zr. This follows from distributions of single-proton spectroscopic factors over final states in Y isotopes: while in ^{89,91,93}Y one can observe one-proton transfers with $l = 4$, $j = 9/2$ and spectroscopic factors $S^{-}(E_x)$ = 0.9 - 1.3 to levels in the excitation energy range 0.5 - 0.9 MeV, similar transfers to the states of ^{95}Y nucleus are not observed at all. It means that a rearrangement of nuclear structure takes place in ^{96}Zr so that this nucleus becomes stiffer and, probably, its shape becomes closer to a spherical one. This feature is typical for a magic nucleus, thus we conclude that N = 56 is a magic number for a nucleus with Z = 40.

TABLE 3. Nucleon occupation probabilities N_{nlj} and single-particle energies $-E_{nlj}$ (MeV) of proton orbits in nuclei $^{90,92,94,96}Zr$.

Nlj	**$N_{nl}j$-E_{nlj}**	**^{90}Zr**	**^{92}Zr**	**^{94}Zr**	**^{96}Zr**
$1g_{9/2}$	N_{nlj}	0.06(5)	0.08(5)	0.09(5)	0.00(0)
	$-E_{nlj}$	5.41(54)	4.98(142)	6.74(80)	7.48(750
$2p_{1/2}$	N_{nlj}	0.58(5)	0.49(3)	0.75(5)	0.81(5)
	$-E_{nlj}$	6.97(70)	7.66(77)	9.37(94)	10.59(106)
$1f_{5/2}$	N_{nlj}	1.00(2)	1.00(2)	1.00(2)	0.94(5)
	$-E_{nlj}$	10.37(110)	10.93(110)	11.49(115)	12.17(122)
$2p_{3/2}$	N_{nlj}	-	-	0.87(5)	-
	$-E_{nlj}$	-	-	11.11(112)	-

It is worthwhile to point out that the number N = 56 is not a magic one combining with other Z values, i.e. for Mo, Ru isotopes, etc. This fact forces us to pay attention to a relation between numbers 40 and 56. Let us note that 56 is equal to 2 × 28, and 40 is equal to 2×20 and then we follow along the way of an analogy between ^{96}Zr and ^{48}Ca. Indeed, the analogy goes quite far, if we consider a data on decays of these two nuclei. Both nuclei, ^{48}Ca and ^{96}Zr, decay via $2\beta^{-}$ mode – quite rare decay, which is less than 1% of all type decays, and $T_{1/2}(^{48}\mathrm{Ca}) = (4.2^{+3.3}_{-1.3}) \times 10^{19}$ years[7], $T_{1/2}(^{96}\mathrm{Zr})=(2.1^{+0.8\ (stat)}_{-0.4\ (stat)} \pm 0.2(\mathrm{syst})) \times 10^{19}$ years[8]. This is really fantastic coincidence: one nucleus is twice as large as the other one, and both of them decay via the same rare mode. Moreover, the half-life time of the heavier is exactly one half of the lighter.

All these facts can be explained if one supposes the existence of an additional interaction between closed structures Z = 20 and N = 28 in the nuclei ^{48}Ca and ^{96}Zr. The nucleus ^{48}Ca is known as a neutron-rich nucleus although it is quite stable. Interaction between the proton Z = 20 and the neutron N = 28 closed structures can be responsible for this specific stability.

At least two heuristic schemes of a coupling between proton and neutron subsystems can be proposed in the framework of the above assumption: a compound cluster model and a "nuclear crystal" model.

The first model (see Fig.3) supposes two levels of interactions of cluster-like structures.

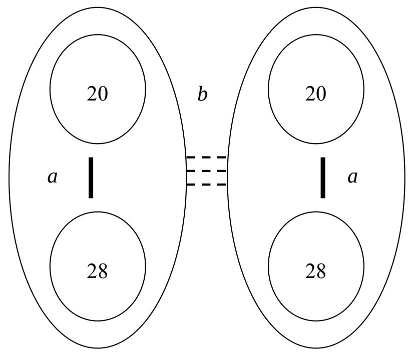


FIGURE 3. A scheme of ^{96}Zr compound cluster model.

The interaction $\mathcal{A}$ couples Z = 20 and N = 28 structures to ^{48}Ca, and its destroying leads to $2\beta^-$– decay with half-life 4.2×10^{19} years. The interaction $\mathcal{B}$ couples "clusters" ^{48}Ca to the ^{96}Zr nucleus. The interaction $\mathcal{B}$ is supposed to be stronger than the interaction $\mathcal{A}$, and destroying one of two $\mathcal{A}$ -interactions leads to destruction of the whole system and to $2\beta^-$– decay with total half-life 2.1×10^{19} years.

The second model supposes two-valent coupling between Z = 20 and N = 28 structures in ^{48}Ca (Fig.4a). ^{96}Zr nucleus is constructed from these two-valent structures like a molecule (Fig.4b). Thus, in both cases, ^{48}Ca and ^{96}Zr, one gets systems with additional stiffness that could be characterized as “nuclear crystal”.

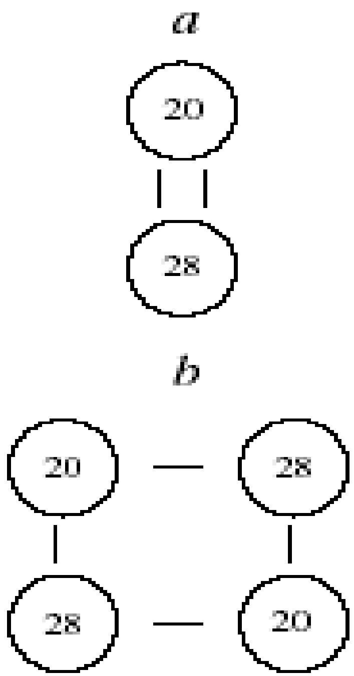
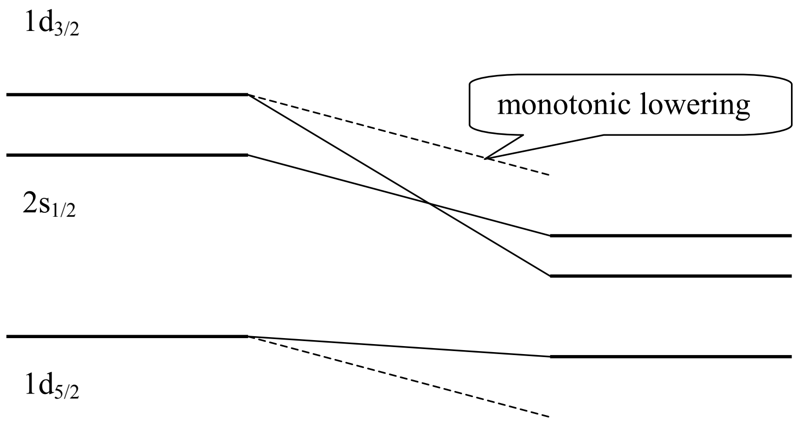


FIGURE 4. A two-valent coupling model: a - ^{48}Ca; b - ^{96}Zr.

POSITIONS OF PROTON SUBSHELLS IN CA ISOTOPES

In Table 4 one-nucleon occupation probabilities as well as single-particle energies of proton orbitals in nuclides ^{40,42,44,46,48}Ca obtained from pick-up, stripping, and spin value data are presented. One can observe the inversion of the $1d_{3/2}$ and $2s_{1/2}$ subshells in ^{48}Ca isotope. This peculiarity explains irregularities in spin-parity values of the ground states K isotopes: ^{39,41,43,45}K the ground states are $J^{\pi} = 3/2^{+}$, whereas ^{47}K ground state is $1/2^{+}$. To describe the placement of proton subshells in ^{48}Ca and, in particular, the inversion of $1d_{3/2}$ - $2s_{1/2}$ subshells, it was assumed that a proton spin-orbit splitting decreases in this nucleus.



This hypothesis was tested by calculations within a dispersion optical model for ^{40,42,44,46,48}Ca[8)] and it was shown that this assumption allows one to describe the inversion adequately.

TABLE 4. Nucleon occupation probabilities N_{nlj} (upper numbers) and single-particle energies $-E_{nlj}$ (MeV) of proton orbits in nuclei ^{40,42,44,46,48}Ca.

	^{40}Ca	^{42}Ca	^{44}Ca	^{46}Ca	^{48}Ca
$1f_{5/2}$	- -	- -	- -	- -	0.00 3.81(12)
$2p_{1/2}$	0.00 -2.38 (24)	- -	- -	- -	0.01 (1) 2.35 (68)
$2p_{3/2}$	0.09 (0.02) 0.73 (29)	0.02 (1) 1.30 (18)	0.05 (2) 4.99 (51)	- -	0.01 (1) 3.95 (53)
$1f_{7/2}$	0.06 (2) 1.67 (22)	0.08 (3) 4.09 (45)	0.13 (3) 7.68 (78)	0.02 (2) 7.89(99)	0.02 (2) 8.62 (100)
$1d_{3/2}$	0.97 (3) 9.52 (152)	0.76 (7) 10.03 (150)	0.72 (7) 10.81 (108)	0.94 (4) 13.53 (138)	0.94 (5) 15.96 (100)
$2s_{1/2}$	1.00 10.94 (109)	0.90 (5) > 11.29	0.77 (7) 11.39 (114)	0.93 (4) 13.94 (139)	0.84 (9) 14.41 (158)
$1d_{5/2}$	0.96 (2) 14.32 (143)	- -	- -	- -	- -

CONCLUSIONS

On the base of the nuclear spectroscopy data analysis new interesting information about the single-particle structure of the Zr and Ca isotopes is obtained. The most important conclusions are the following:

- Behavior of the energies of the first 2^+ levels in Zr isotopes is explained in the framework of a shell model approach. A strong separation of the neutron $2d_{5/2}$ subshell in ^{96}Zr (like it is with the $1f_{7/2}$ subshell in ^{48}Ca) is found, so that the neutron number N = 56 can be considered as a magic one in a nucleus with Z = 40. To explain some correlations in decay properties of ^{48}Ca and ^{96}Zr an additional interaction between closed structures of 20- and 28 nucleons is proposed.
- Irregularities of the ground state spins along the K isotopic chain are explained in the framework of a shell model approach by the inversion of the $1d_{3/2}$ and $2s_{1/2}$ proton orbitals.

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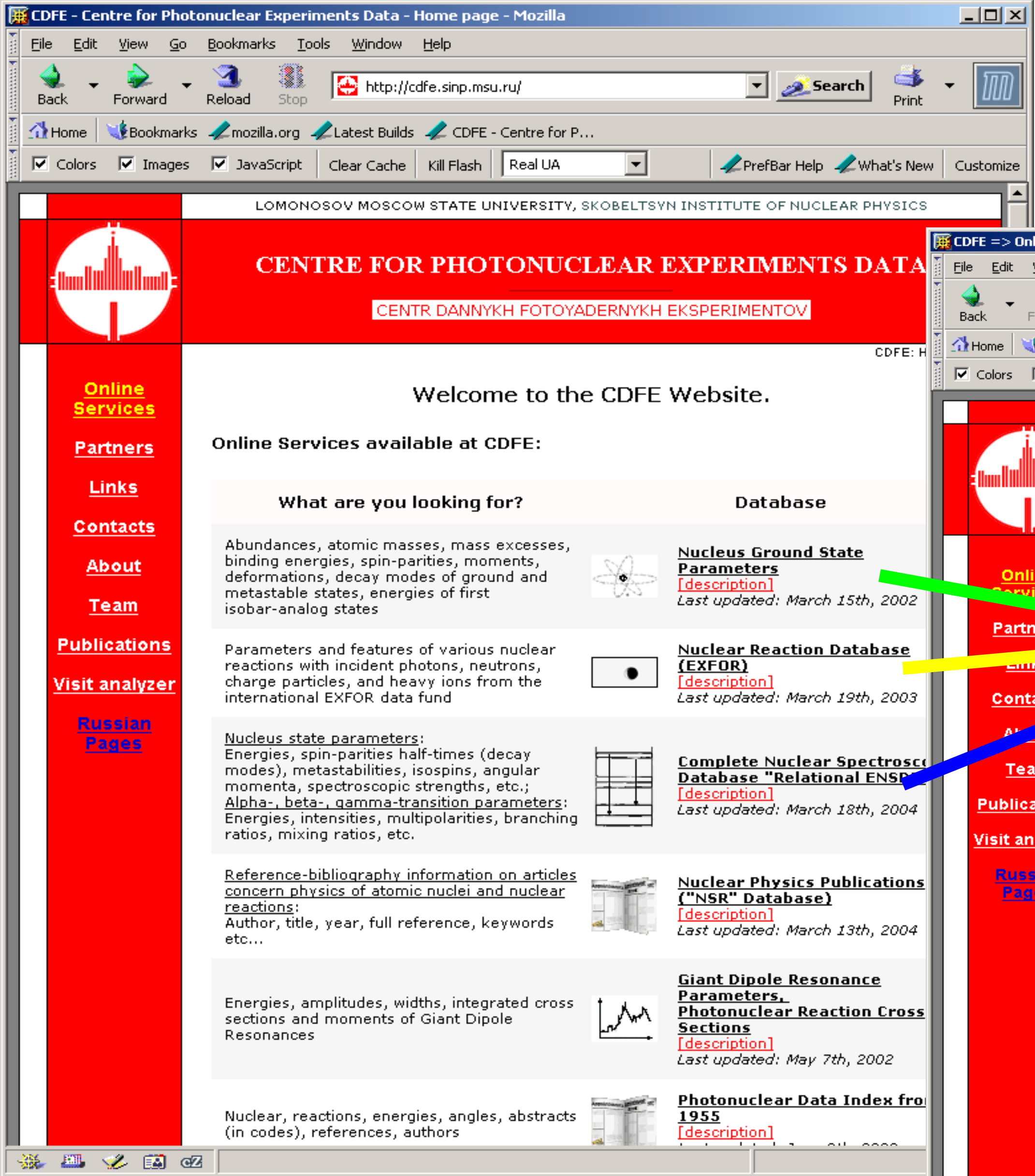
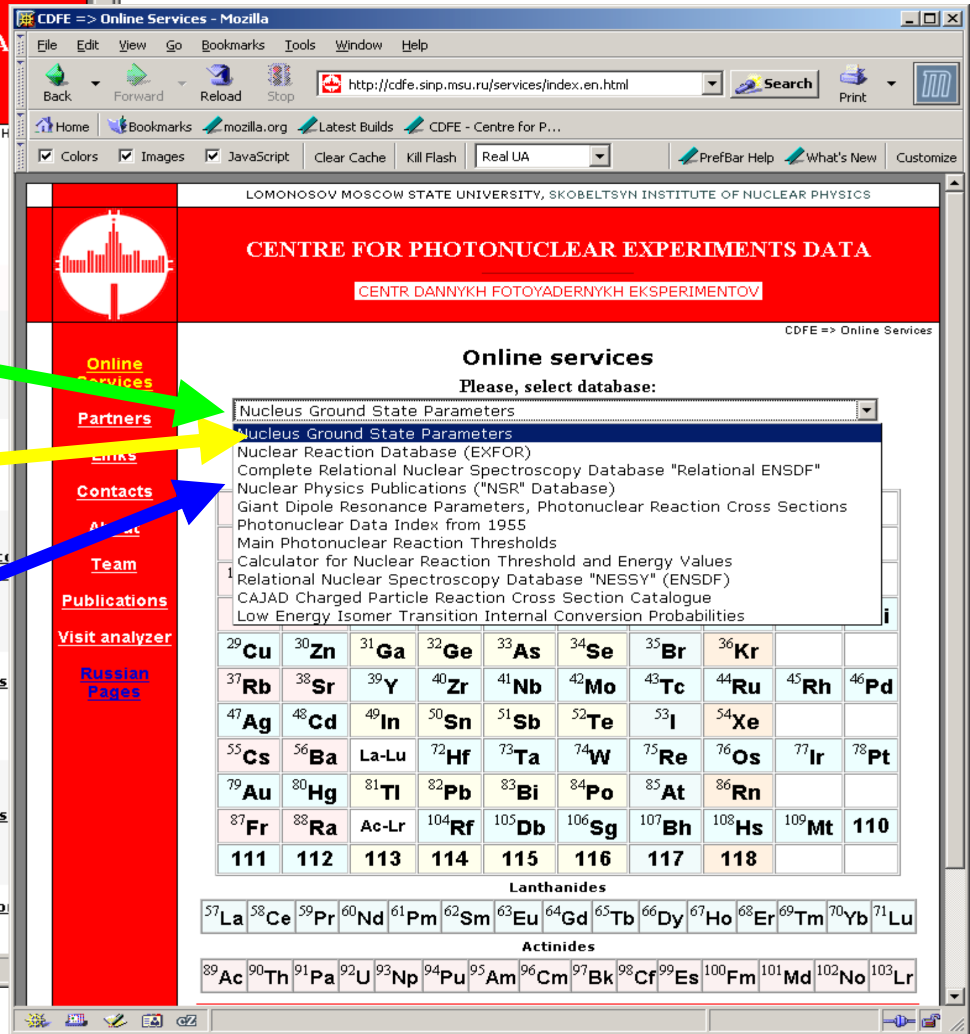
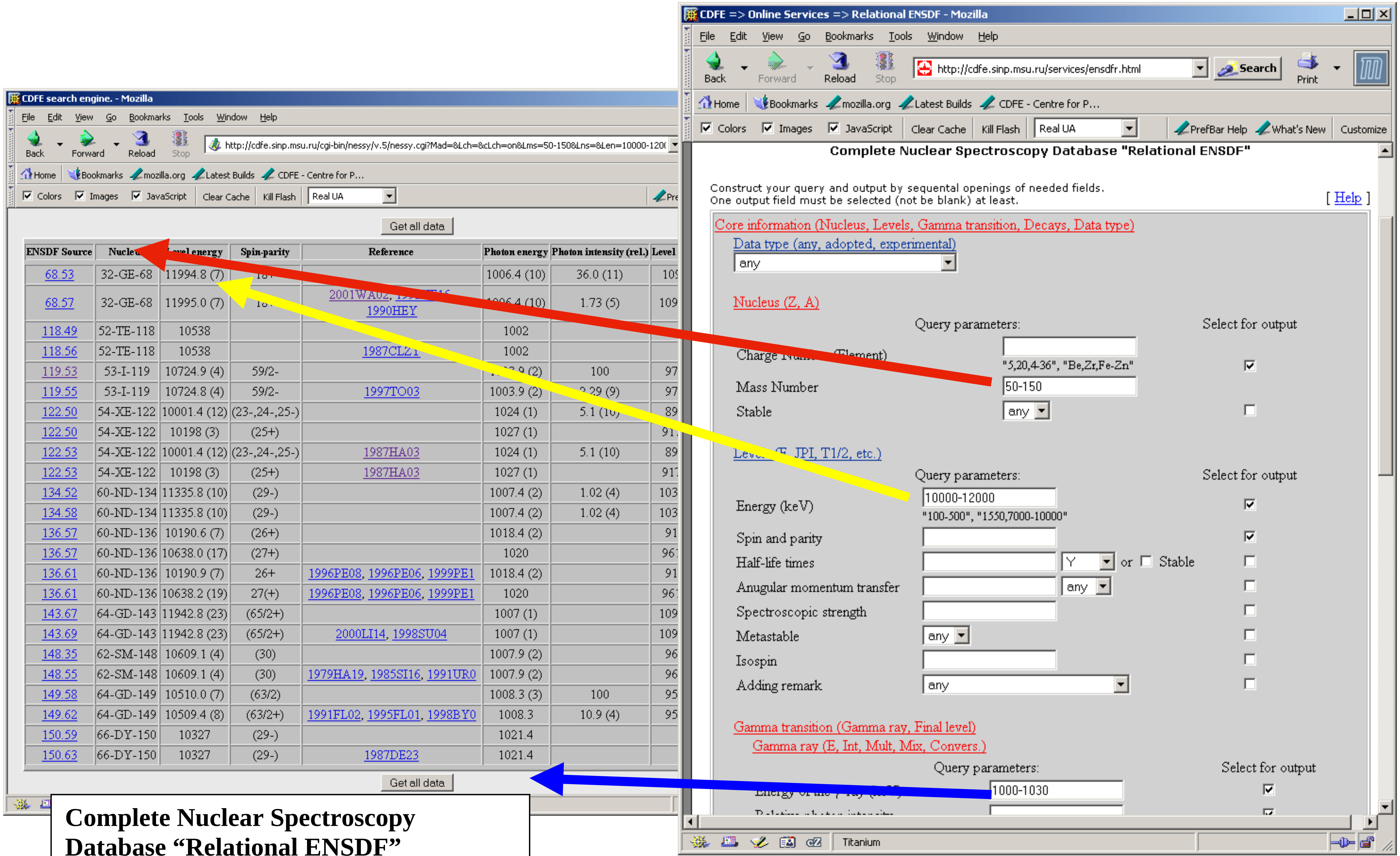
The MSU SINP Centre for Photoniuclear Experiments Data (Centr Dannykh Fotoyadernykh Eksperimentov - CDFE) Web-site main page:

http://cdfe.sinp.msu.ru

The CDFE databases – online services.







ENSDF Source	Nucleus	Level energy	Spin-parity	Reference	Photon energy	Photon intensity (rel.)	Level
68.53	32-GE-68	11994.8 (7)	18+		1006.4 (10)	36.0 (11)	10[illegible]
68.57	32-GE-68	11995.0 (7)	18+	2001WA02, [illegible], 1990HEY	1006.4 (10)	1.73 (5)	109
118.49	52-TE-118	10538			1002		
118.56	52-TE-118	10538		1987CLZY	1002		
119.53	53-I-119	10724.9 (4)	59/2-		1[illegible]3.9 (2)	100	97
119.55	53-I-119	10724.8 (4)	59/2-	1997TO03	1003.9 (2)	2.29 (9)	97
122.50	54-XE-122	10001.4 (12)	(23-,24-,25-)		1024 (1)	5.1 (10)	89
122.50	54-XE-122	10198 (3)	(25+)		1027 (1)		91
122.53	54-XE-122	10001.4 (12)	(23-,24-,25-)	1987HA03	1024 (1)	5.1 (10)	89
122.53	54-XE-122	10198 (3)	(25+)	1987HA03	1027 (1)		91
134.52	60-ND-134	11335.8 (10)	(29-)		1007.4 (2)	1.02 (4)	103
134.58	60-ND-134	11335.8 (10)	(29-)		1007.4 (2)	1.02 (4)	103
136.57	60-ND-136	10190.6 (7)	(26+)		1018.4 (2)		91
136.57	60-ND-136	10638.0 (17)	(27+)		1020		96
136.61	60-ND-136	10190.9 (7)	26+	1996PE08, 1996PE06, 1999PE1	1018.4 (2)		91
136.61	60-ND-136	10638.2 (19)	27(+)	1996PE08, 1996PE06, 1999PE1	1020		96
143.67	64-GD-143	11942.8 (23)	(65/2+)		1007 (1)		109
143.69	64-GD-143	11942.8 (23)	(65/2+)	2000LI14, 1998SU04	1007 (1)		109
148.35	62-SM-148	10609.1 (4)	(30)		1007.9 (2)		96
148.55	62-SM-148	10609.1 (4)	(30)	1979HA19, 1985SI16, 1991UR0	1007.9 (2)		96
149.58	64-GD-149	10510.0 (7)	(63/2)		1008.3 (3)	100	95
149.62	64-GD-149	10509.4 (8)	(63/2+)	1991FL02, 1995FL01, 1998BY0	1008.3	10.9 (4)	95
150.59	66-DY-150	10327	(29-)		1021.4		
150.63	66-DY-150	10327	(29-)	1987DE23	1021.4		

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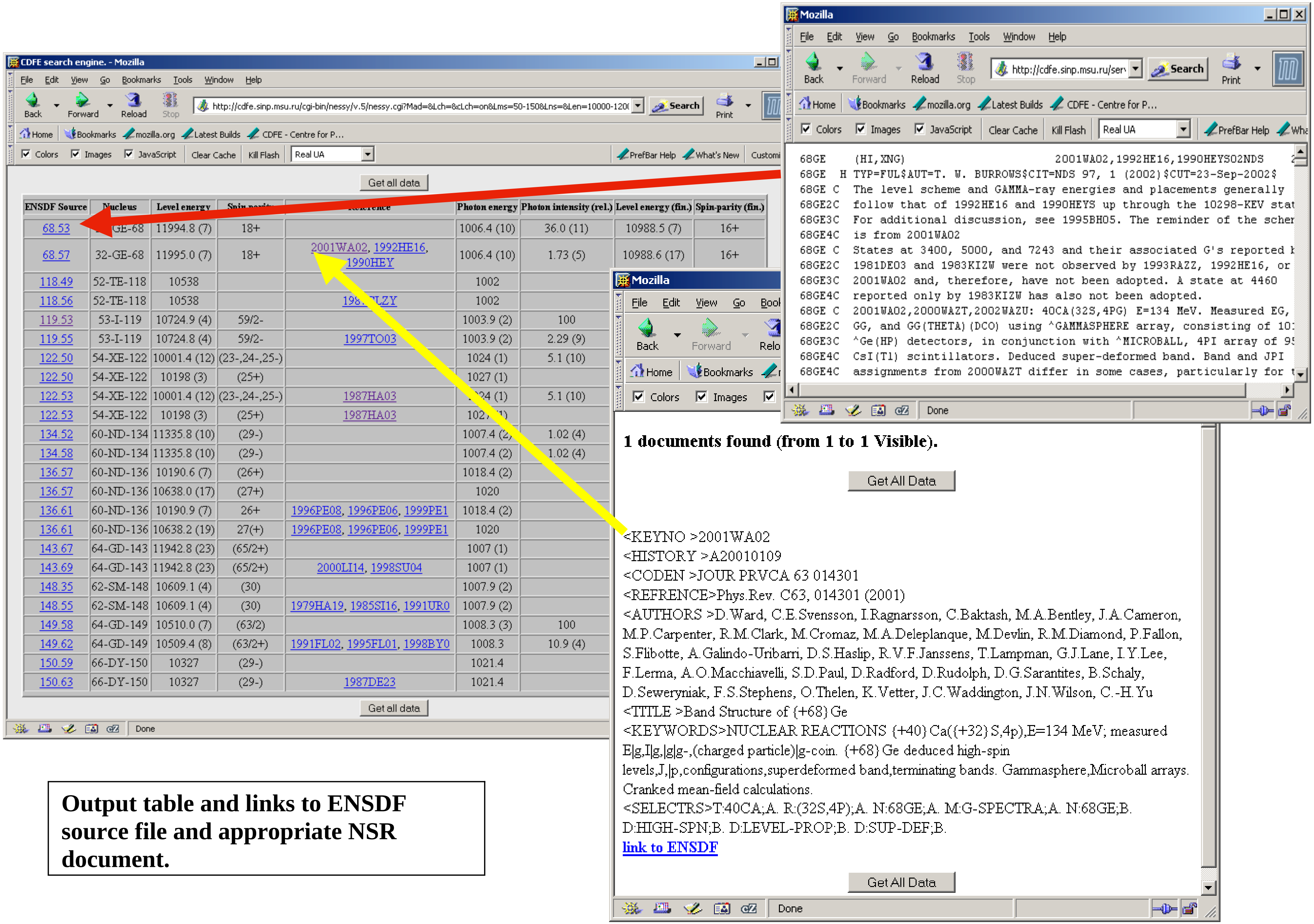

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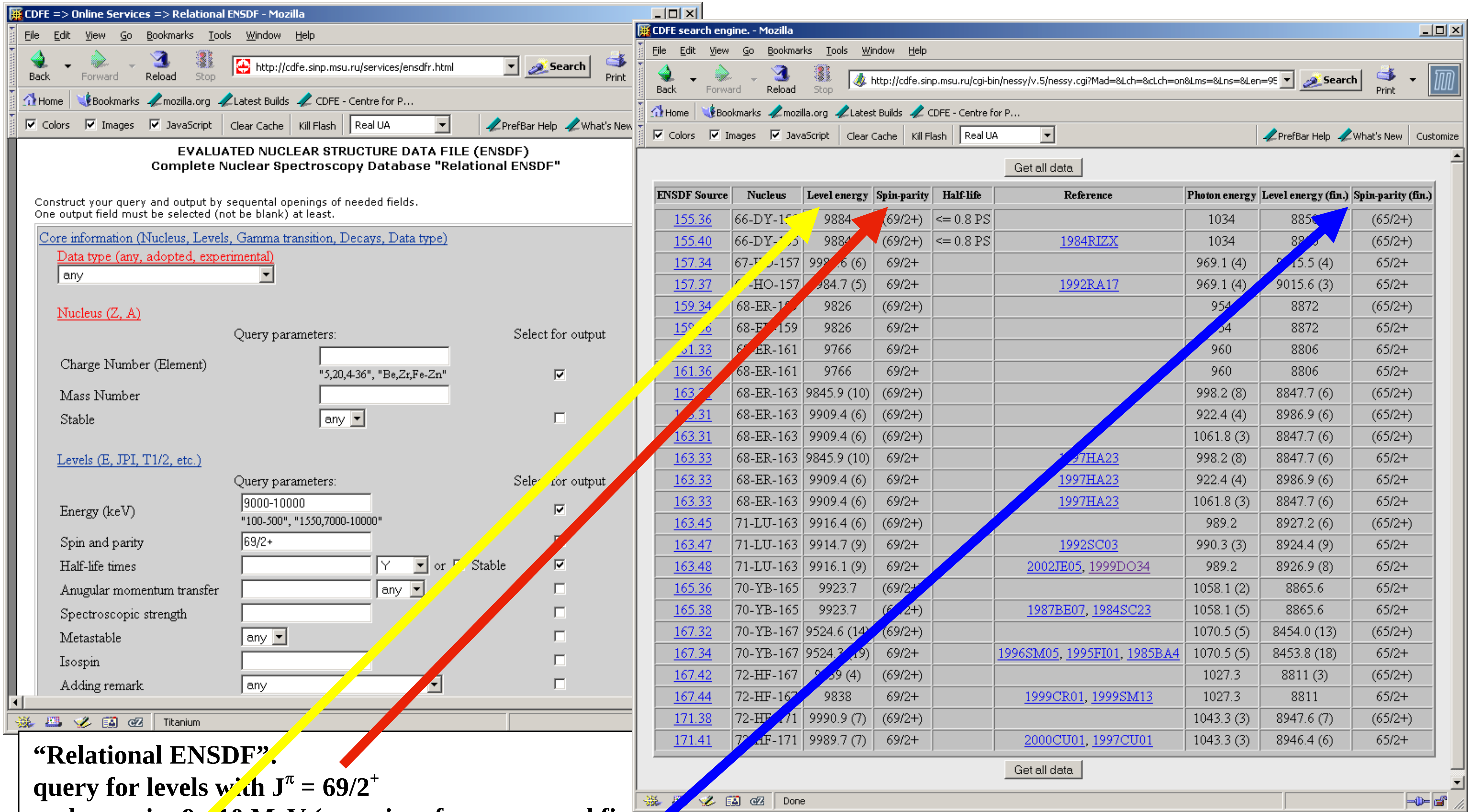

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155.40	[illegible]	9884	(69/2+)	<= 0.8 PS	1984RIZX	1034	[illegible]	(65/2+)
157.34	[illegible]	[illegible]	69/2+			969.1 (4)	[illegible]	65/2+
157.37	[illegible]	[illegible]	69/2+		1992RA17	969.1 (4)	9015.6 (3)	65/2+
159.34	[illegible]	9826	(69/2+)			[illegible]	8872	(65/2+)
[illegible]	[illegible]	9826	69/2+			[illegible]	8872	65/2+
[illegible]	[illegible]	9766	69/2+			960	8806	65/2+
161.36	68-ER-161	9766	69/2+			960	8806	65/2+
[illegible]	68-ER-163	9845.9 (10)	(69/2+)			998.2 (8)	8847.7 (6)	(65/2+)
[illegible]	68-ER-163	9909.4 (6)	(69/2+)			922.4 (4)	8986.9 (6)	(65/2+)
163.31	68-ER-163	9909.4 (6)	(69/2+)			1061.8 (3)	8847.7 (6)	(65/2+)
163.33	68-ER-163	9845.9 (10)	69/2+		[illegible]	998.2 (8)	8847.7 (6)	65/2+
163.33	68-ER-163	9909.4 (6)	69/2+		1997HA23	922.4 (4)	8986.9 (6)	65/2+
163.33	68-ER-163	9909.4 (6)	69/2+		1997HA23	1061.8 (3)	8847.7 (6)	65/2+
163.45	71-LU-163	9916.4 (6)	(69/2+)			989.2	8927.2 (6)	(65/2+)
163.47	71-LU-163	9914.7 (9)	69/2+		1992SC03	990.3 (3)	8924.4 (9)	65/2+
163.48	71-LU-163	9916.1 (9)	69/2+		2002JE05, 1999DO34	989.2	8926.9 (8)	65/2+
165.36	70-YB-165	9923.7	[illegible]			1058.1 (2)	8865.6	65/2+
165.38	70-YB-165	9923.7	[illegible]		1987BE07, 1984SC23	1058.1 (5)	8865.6	65/2+
167.32	70-YB-167	[illegible]	(69/2+)			1070.5 (5)	8454.0 (13)	(65/2+)
167.34	70-YB-167	[illegible]	69/2+		1996SM05, 1995FI01, 1985BA4	1070.5 (5)	8453.8 (18)	65/2+
167.42	72-HF-167	[illegible]	(69/2+)			1027.3	8811 (3)	(65/2+)
167.44	[illegible]	9838	69/2+		1999CR01, 1999SM13	1027.3	8811	65/2+
171.38	[illegible]	9990.9 (7)	(69/2+)			1043.3 (3)	8947.6 (7)	(65/2+)
171.41	[illegible]	9989.7 (7)	69/2+		2000CU01, 1997CU01	1043.3 (3)	8946.4 (6)	65/2+

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and energies 9 - 10 MeV (energies of gammas and final level energies and J^{π} are requested also).

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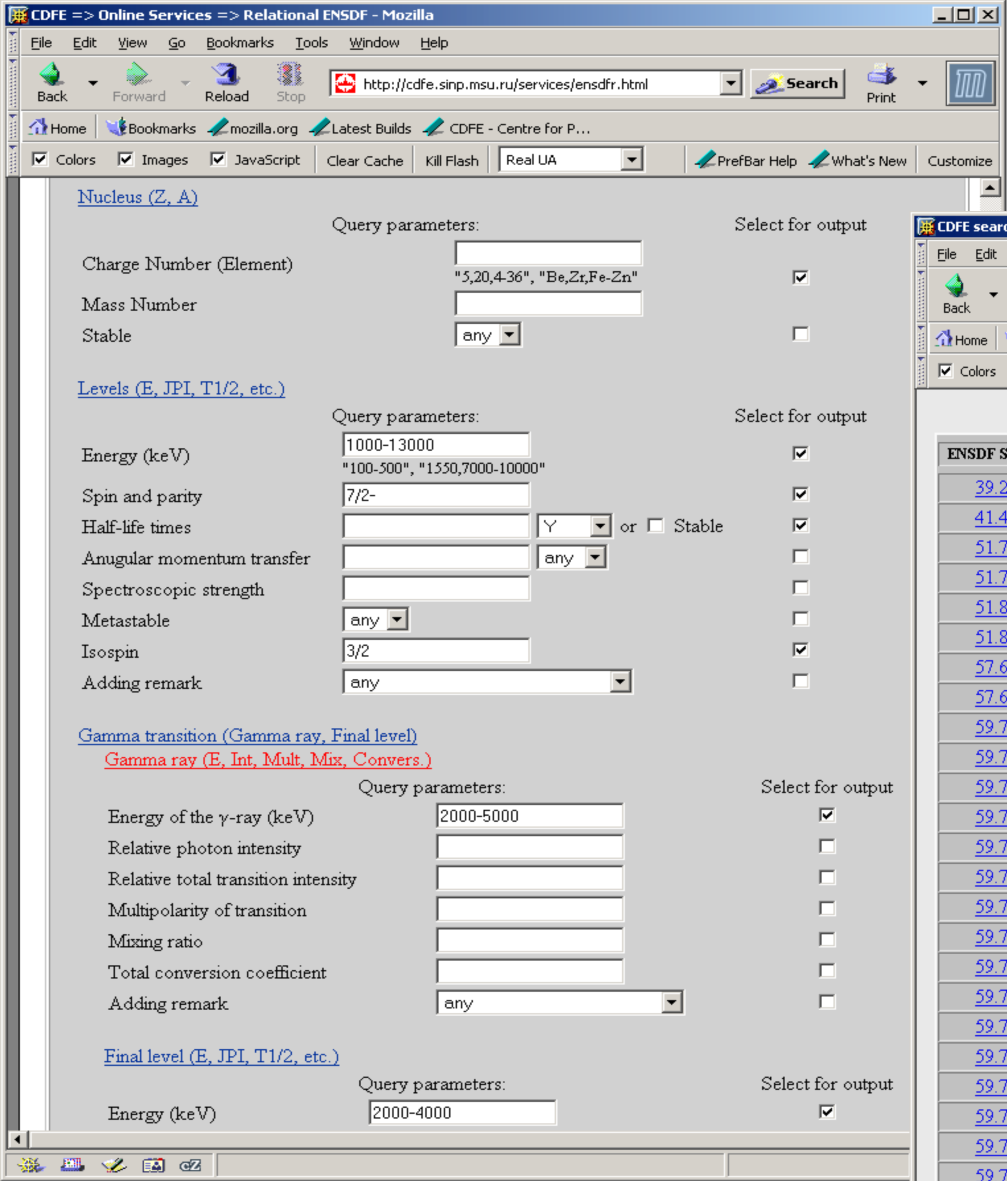
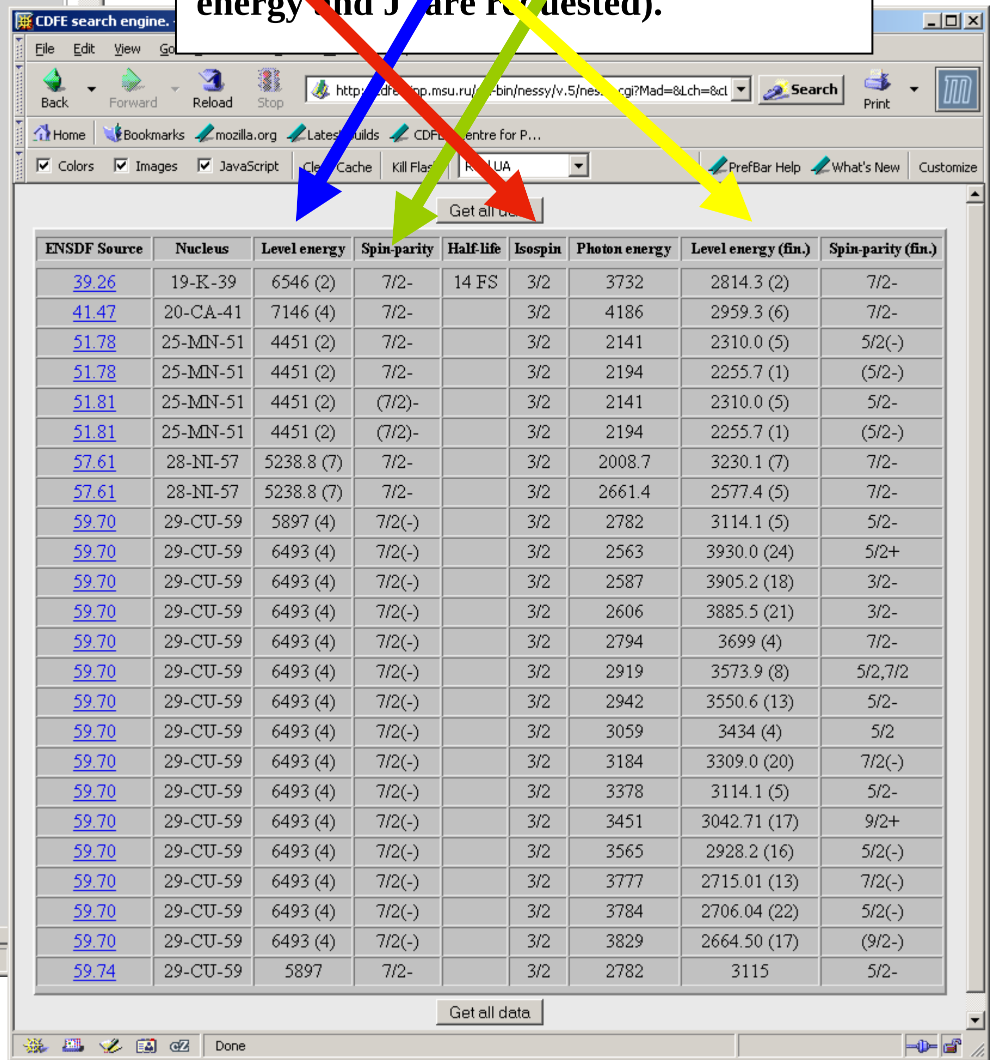
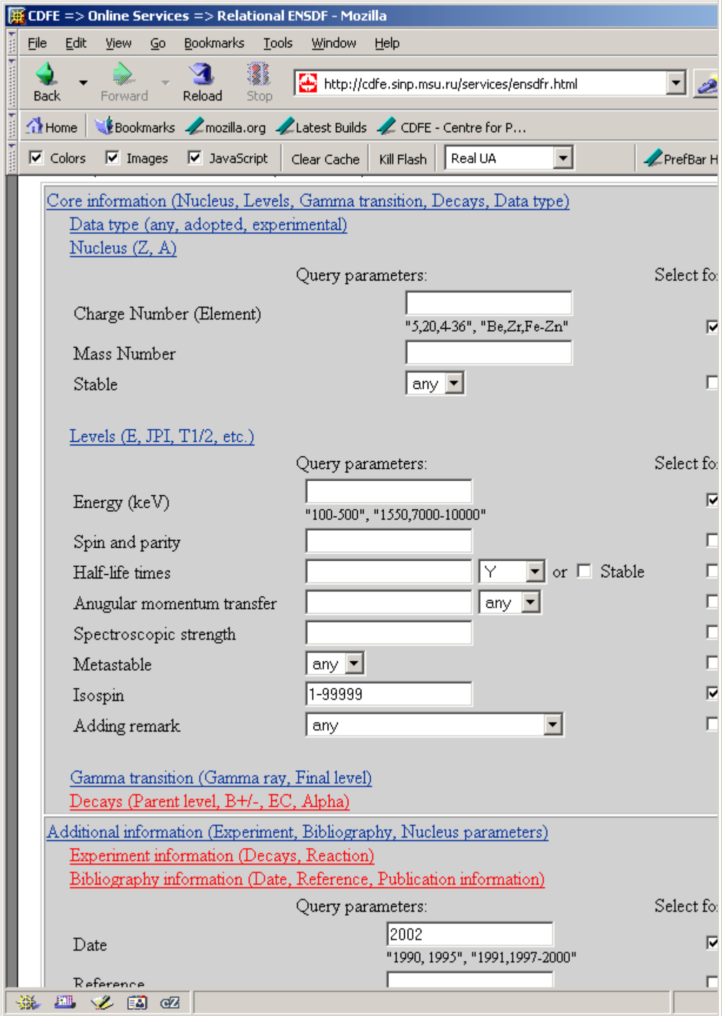
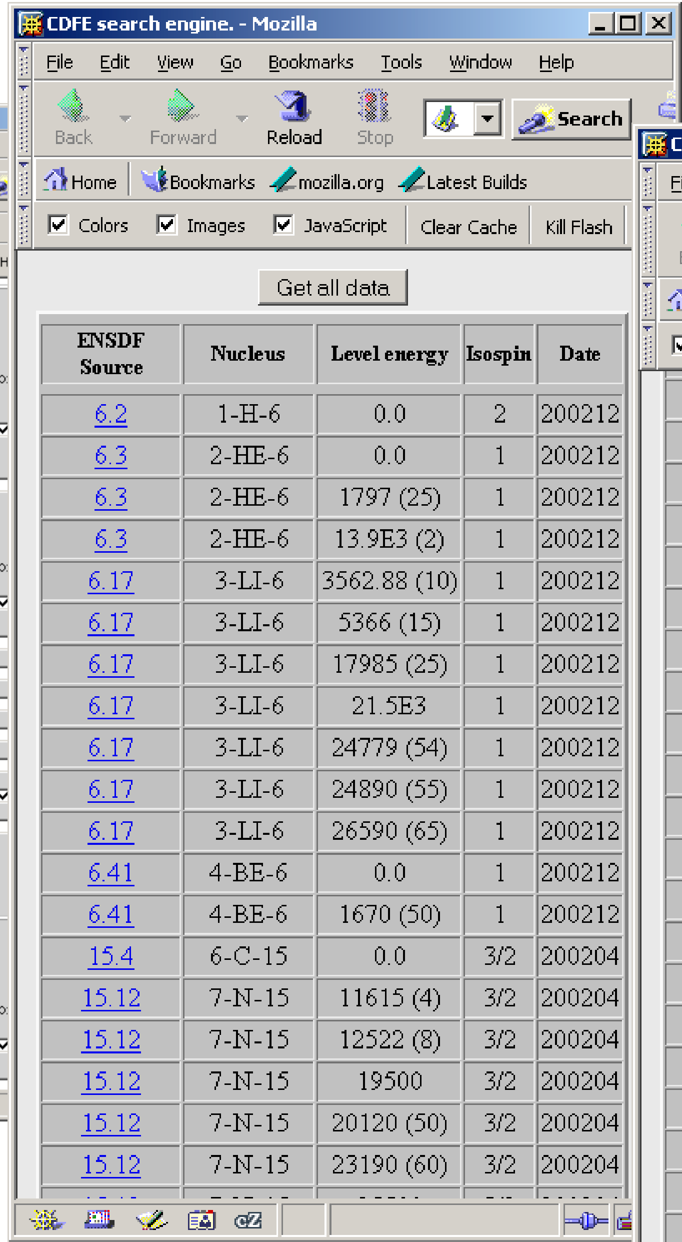




ENSDF Source	Nucleus	Level energy	Spin-parity	Half-life	Isospin	Photon energy	Level energy (fin.)	Spin-parity (fin.)
39.26	19-K-39	6546 (2)	7/2-	14 FS	3/2	3732	2814.3 (2)	7/2-
41.47	20-CA-41	7146 (4)	7/2-		3/2	4186	2959.3 (6)	7/2-
51.78	25-MN-51	4451 (2)	7/2-		3/2	2141	2310.0 (5)	5/2(-)
51.78	25-MN-51	4451 (2)	7/2-		3/2	2194	2255.7 (1)	(5/2-)
51.81	25-MN-51	4451 (2)	(7/2)-		3/2	2141	2310.0 (5)	5/2-
51.81	25-MN-51	4451 (2)	(7/2)-		3/2	2194	2255.7 (1)	(5/2-)
57.61	28-NI-57	5238.8 (7)	7/2-		3/2	2008.7	3230.1 (7)	7/2-
57.61	28-NI-57	5238.8 (7)	7/2-		3/2	2661.4	2577.4 (5)	7/2-
59.70	29-CU-59	5897 (4)	7/2(-)		3/2	2782	3114.1 (5)	5/2-
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	2563	3930.0 (24)	5/2+
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	2587	3905.2 (18)	3/2-
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	2606	3885.5 (21)	3/2-
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	2794	3699 (4)	7/2-
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	2919	3573.9 (8)	5/2,7/2
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	2942	3550.6 (13)	5/2-
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	3059	3434 (4)	5/2
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	3184	3309.0 (20)	7/2(-)
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	3378	3114.1 (5)	5/2-
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	3451	3042.71 (17)	9/2+
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	3565	2928.2 (16)	5/2(-)
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	3777	2715.01 (13)	7/2(-)
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	3784	2706.04 (22)	5/2(-)
59.70	29-CU-59	6493 (4)	7/2(-)		3/2	3829	2664.50 (17)	(9/2-)
59.74	29-CU-59	5897	7/2-		3/2	2782	3115	5/2-





ENSDF Source	Nucleus	Level energy	Isospin	Date
6.2	1-H-6	0.0	2	200212
6.3	2-HE-6	0.0	1	200212
6.3	2-HE-6	1797 (25)	1	200212
6.3	2-HE-6	13.9E3 (2)	1	200212
6.17	3-LI-6	3562.88 (10)	1	200212
6.17	3-LI-6	5366 (15)	1	200212
6.17	3-LI-6	17985 (25)	1	200212
6.17	3-LI-6	21.5E3	1	200212
6.17	3-LI-6	24779 (54)	1	200212
6.17	3-LI-6	24890 (55)	1	200212
6.17	3-LI-6	26590 (65)	1	200212
6.41	4-BE-6	0.0	1	200212
6.41	4-BE-6	1670 (50)	1	200212
15.4	6-C-15	0.0	3/2	200204
15.12	7-N-15	11615 (4)	3/2	200204
15.12	7-N-15	12522 (8)	3/2	200204
15.12	7-N-15	19500	3/2	200204
15.12	7-N-15	20120 (50)	3/2	200204
15.12	7-N-15	23190 (60)	3/2	200204

117.50	51-SB-117	12290 (15)	17/2	200205
117.50	51-SB-117	12455 (15)	17/2	200205
117.50	51-SB-117	12587 (15)	17/2	200205
120.40	51-SB-120	10204 (30)	10	200209
120.40	51-SB-120	11354 (30)	10	200209
120.40	51-SB-120	11994 (30)	10	200209
120.40	51-SB-120	12314 (30)	10	200209
120.40	51-SB-120	12504 (30)	10	200209
120.40	51-SB-120	12604 (30)	10	200209
120.40	51-SB-120	12784 (30)	10	200209
120.40	51-SB-120	12914 (30)	10	200209
120.40	51-SB-120	13034 (30)	10	200209
120.40	51-SB-120	13124 (30)	10	200209
143.14	58-CE-143	0.0	27/2	200201
143.14	58-CE-143	808.2 (3)	27/2	200201
143.14	58-CE-143	862.1 (3)	27/2	200201
143.14	58-CE-143	1172.5 (3)	27/2	200201
143.14	58-CE-143	1195 (10)	27/2	200201
143.14	58-CE-143	1298 (5)	27/2	200201
170.14	69-TM-170	15492 (7)	17	200211
170.35	71-LU-170	12855 (20)	15	200211

Relational ENSDF query for all nuclear levels included into the ENSDF in 2002 for which information on isospin value is available.

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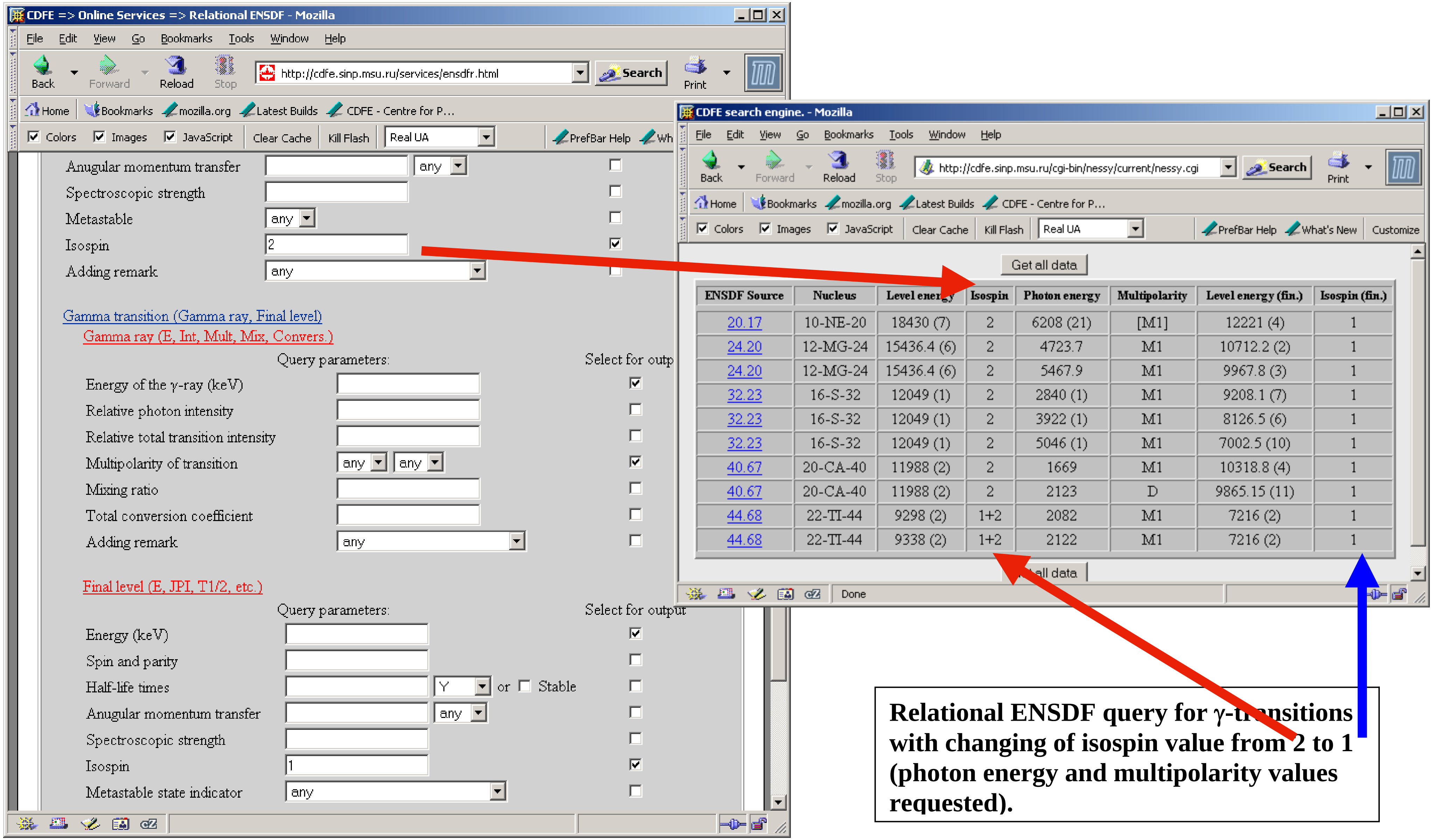
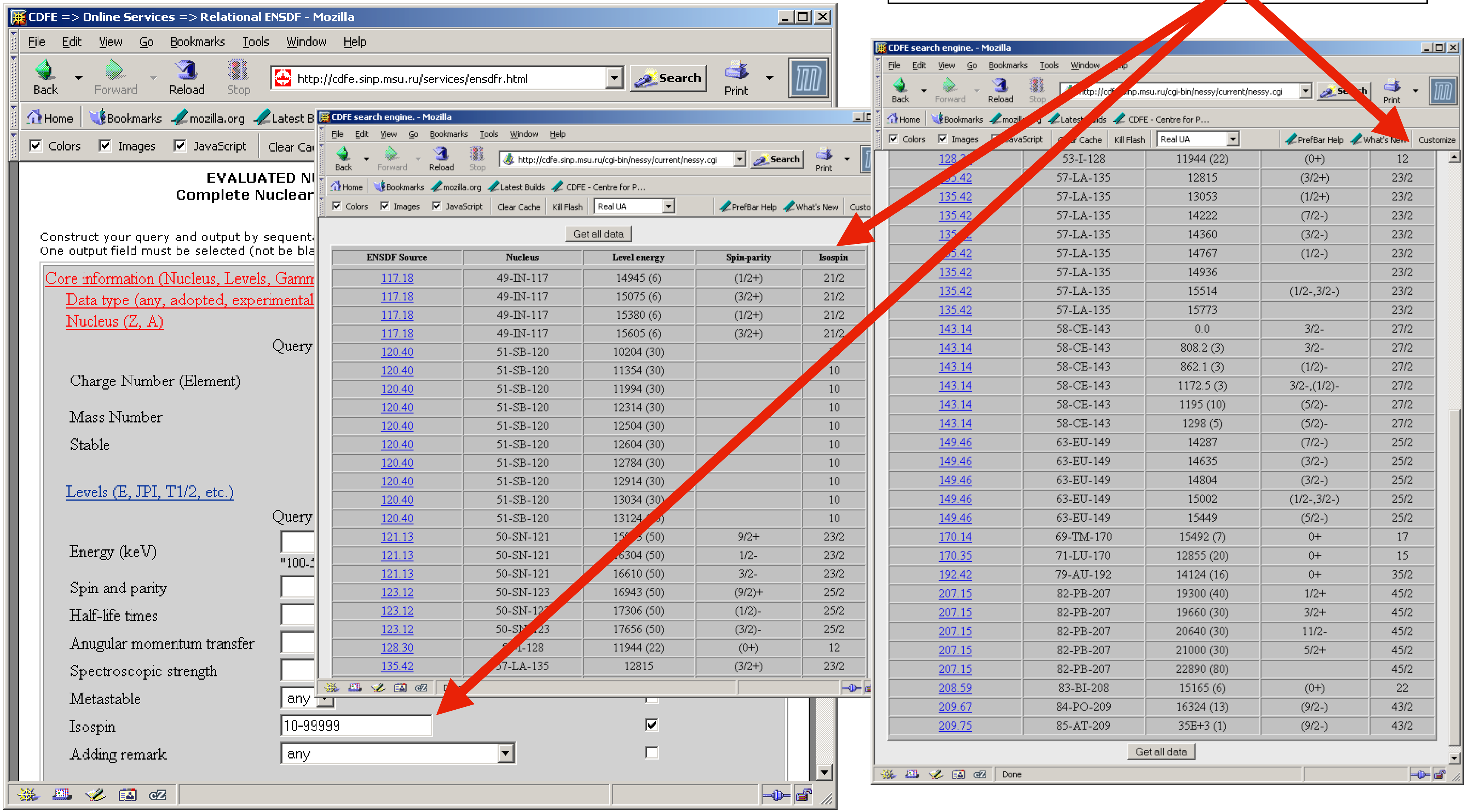


ENSDF Source	Nucleus	Level energy	Isospin	Photon energy	Multipolarity	Level energy (fin.)	Isospin (fin.)
20.17	10-NE-20	18430 (7)	2	6208 (21)	[M1]	12221 (4)	1
24.20	12-MG-24	15436.4 (6)	2	4723.7	M1	10712.2 (2)	1
24.20	12-MG-24	15436.4 (6)	2	5467.9	M1	9967.8 (3)	1
32.23	16-S-32	12049 (1)	2	2840 (1)	M1	9208.1 (7)	1
32.23	16-S-32	12049 (1)	2	3922 (1)	M1	8126.5 (6)	1
32.23	16-S-32	12049 (1)	2	5046 (1)	M1	7002.5 (10)	1
40.67	20-CA-40	11988 (2)	2	1669	M1	10318.8 (4)	1
40.67	20-CA-40	11988 (2)	2	2123	D	9865.15 (11)	1
44.68	22-TI-44	9298 (2)	1+2	2082	M1	7216 (2)	1
44.68	22-TI-44	9338 (2)	1+2	2122	M1	7216 (2)	1

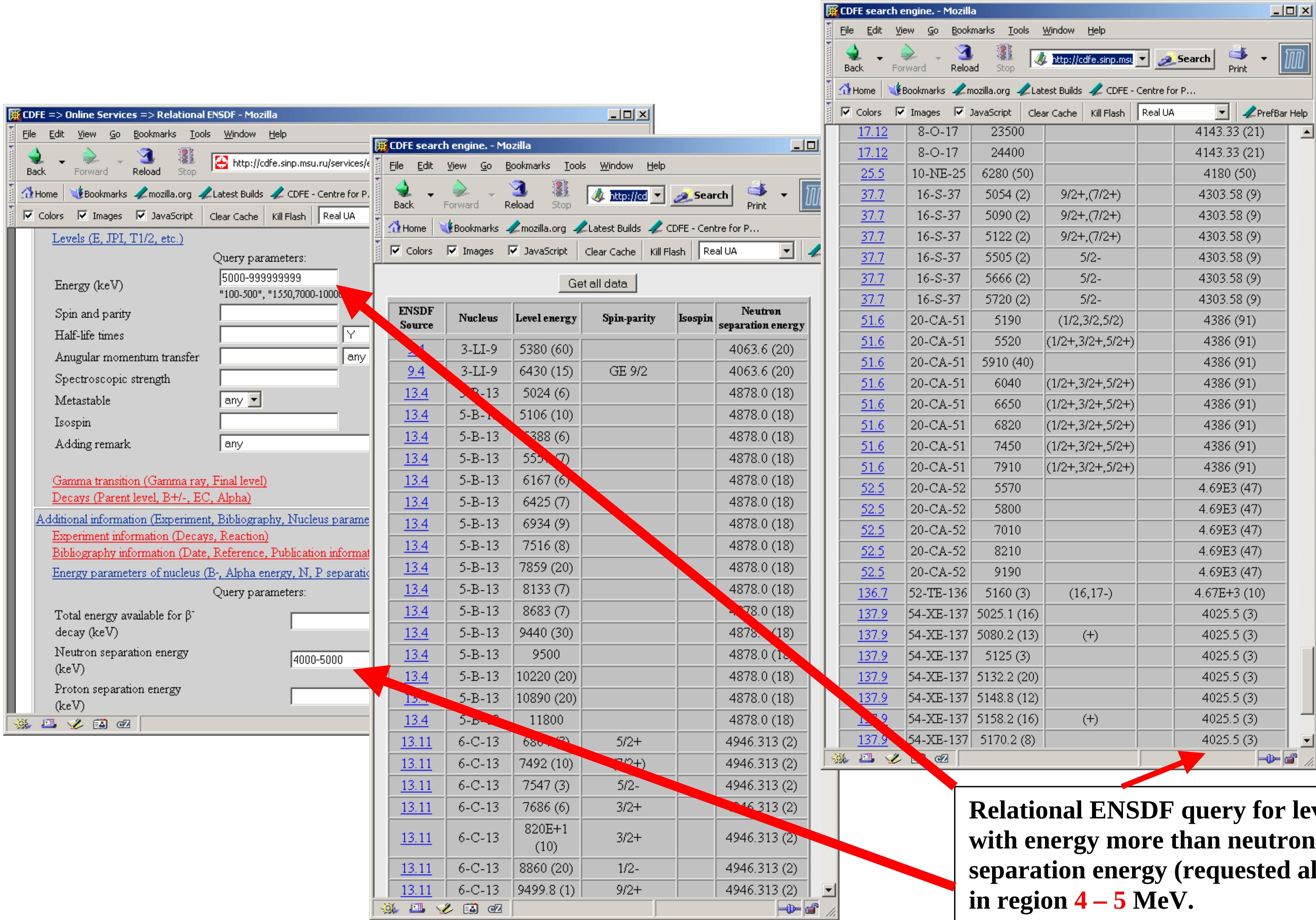
Relational ENSDF query for γ-transitions with changing of isospin value from 2 to 1 (photon energy and multipolarity values requested).

Relational ENSDF query for nuclei with levels having isospin value T ≥ 10.



ENSDF Source	Nucleus	Level energy	Spin-parity	Isospin
117.18	49-IN-117	14945 (6)	(1/2+)	21/2
117.18	49-IN-117	15075 (6)	(3/2+)	21/2
117.18	49-IN-117	15380 (6)	(1/2+)	21/2
117.18	49-IN-117	15605 (6)	(3/2+)	21/2
120.40	51-SB-120	10204 (30)		
120.40	51-SB-120	11354 (30)		10
120.40	51-SB-120	11994 (30)		10
120.40	51-SB-120	12314 (30)		10
120.40	51-SB-120	12504 (30)		10
120.40	51-SB-120	12604 (30)		10
120.40	51-SB-120	12784 (30)		10
120.40	51-SB-120	12914 (30)		10
120.40	51-SB-120	13034 (30)		10
120.40	51-SB-120	13124 [illegible]		10
121.13	50-SN-121	[illegible] (50)	9/2+	23/2
121.13	50-SN-121	[illegible]6304 (50)	1/2-	23/2
121.13	50-SN-121	16610 (50)	3/2-	23/2
123.12	50-SN-123	16943 (50)	(9/2)+	25/2
123.12	50-SN-12[illegible]	17306 (50)	(1/2)-	25/2
123.12	50-S[illegible]23	17656 (50)	(3/2)-	25/2
128.30	[illegible]-128	11944 (22)	(0+)	12
135.42	[illegible]7-LA-135	12815	(3/2+)	23/2

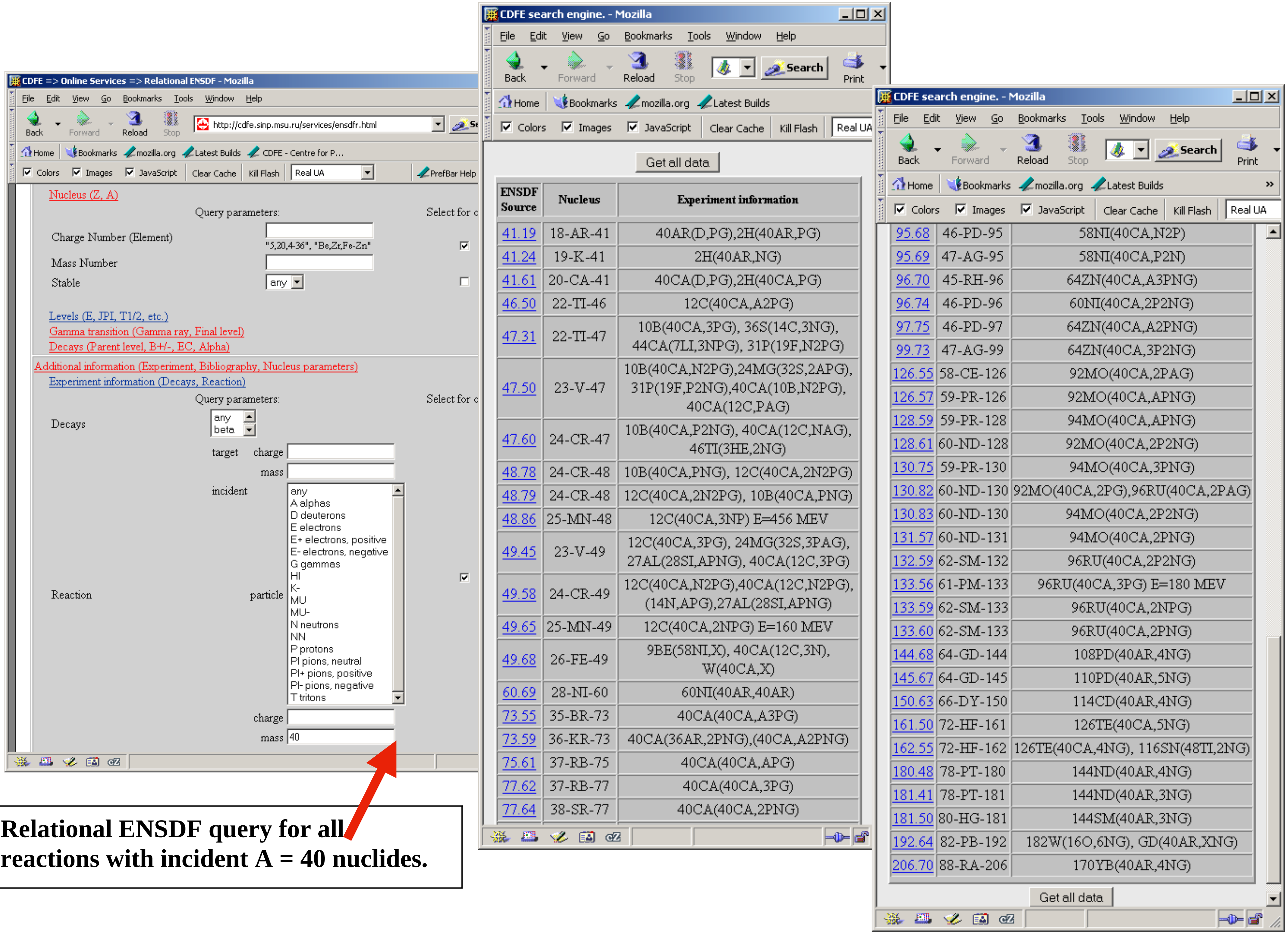
128.[illegible]	53-I-128	11944 (22)	(0+)	12
[illegible]5.42	57-LA-135	12815	(3/2+)	23/2
135.42	57-LA-135	13053	(1/2+)	23/2
135.42	57-LA-135	14222	(7/2-)	23/2
135[illegible]	57-LA-135	14360	(3/2-)	23/2
[illegible]5.42	57-LA-135	14767	(1/2-)	23/2
135.42	57-LA-135	14936		23/2
135.42	57-LA-135	15514	(1/2-,3/2-)	23/2
135.42	57-LA-135	15773		23/2
143.14	58-CE-143	0.0	3/2-	27/2
143.14	58-CE-143	808.2 (3)	3/2-	27/2
143.14	58-CE-143	862.1 (3)	(1/2)-	27/2
143.14	58-CE-143	1172.5 (3)	3/2-,(1/2)-	27/2
143.14	58-CE-143	1195 (10)	(5/2)-	27/2
143.14	58-CE-143	1298 (5)	(5/2)-	27/2
149.46	63-EU-149	14287	(7/2-)	25/2
149.46	63-EU-149	14635	(3/2-)	25/2
149.46	63-EU-149	14804	(3/2-)	25/2
149.46	63-EU-149	15002	(1/2-,3/2-)	25/2
149.46	63-EU-149	15449	(5/2-)	25/2
170.14	69-TM-170	15492 (7)	0+	17
170.35	71-LU-170	12855 (20)	0+	15
192.42	79-AU-192	14124 (16)	0+	35/2
207.15	82-PB-207	19300 (40)	1/2+	45/2
207.15	82-PB-207	19660 (30)	3/2+	45/2
207.15	82-PB-207	20640 (30)	11/2-	45/2
207.15	82-PB-207	21000 (30)	5/2+	45/2
207.15	82-PB-207	22890 (80)		45/2
208.59	83-BI-208	15165 (6)	(0+)	22
209.67	84-PO-209	16324 (13)	(9/2-)	43/2
209.75	85-AT-209	35E+3 (1)	(9/2-)	43/2



ENSDF Source	Nucleus	Level energy	Spin-parity	Isospin	Neutron separation energy
9.4	3-LI-9	5380 (60)			4063.6 (20)
9.4	3-LI-9	6430 (15)	GE 9/2		4063.6 (20)
13.4	5-B-13	5024 (6)			4878.0 (18)
13.4	5-B-13	5106 (10)			4878.0 (18)
13.4	5-B-13	5388 (6)			4878.0 (18)
13.4	5-B-13	55[illegible] (7)			4878.0 (18)
13.4	5-B-13	6167 (6)			4878.0 (18)
13.4	5-B-13	6425 (7)			4878.0 (18)
13.4	5-B-13	6934 (9)			4878.0 (18)
13.4	5-B-13	7516 (8)			4878.0 (18)
13.4	5-B-13	7859 (20)			4878.0 (18)
13.4	5-B-13	8133 (7)			4878.0 (18)
13.4	5-B-13	8683 (7)			4878.0 (18)
13.4	5-B-13	9440 (30)			4878.0 (18)
13.4	5-B-13	9500			4878.0 (18)
13.4	5-B-13	10220 (20)			4878.0 (18)
13.4	5-B-13	10890 (20)			4878.0 (18)
13.4	5-B-13	11800			4878.0 (18)
13.11	6-C-13	680[illegible]	5/2+		4946.313 (2)
13.11	6-C-13	7492 (10)	(7/2+)		4946.313 (2)
13.11	6-C-13	7547 (3)	5/2-		4946.313 (2)
13.11	6-C-13	7686 (6)	3/2+		4946.313 (2)
13.11	6-C-13	820E+1 (10)	3/2+		4946.313 (2)
13.11	6-C-13	8860 (20)	1/2-		4946.313 (2)
13.11	6-C-13	9499.8 (1)	9/2+		4946.313 (2)

17.12	8-O-17	23500			4143.33 (21)
17.12	8-O-17	24400			4143.33 (21)
25.5	10-NE-25	6280 (50)			4180 (50)
37.7	16-S-37	5054 (2)	9/2+,(7/2+)		4303.58 (9)
37.7	16-S-37	5090 (2)	9/2+,(7/2+)		4303.58 (9)
37.7	16-S-37	5122 (2)	9/2+,(7/2+)		4303.58 (9)
37.7	16-S-37	5505 (2)	5/2-		4303.58 (9)
37.7	16-S-37	5666 (2)	5/2-		4303.58 (9)
37.7	16-S-37	5720 (2)	5/2-		4303.58 (9)
51.6	20-CA-51	5190	(1/2,3/2,5/2)		4386 (91)
51.6	20-CA-51	5520	(1/2+,3/2+,5/2+)		4386 (91)
51.6	20-CA-51	5910 (40)			4386 (91)
51.6	20-CA-51	6040	(1/2+,3/2+,5/2+)		4386 (91)
51.6	20-CA-51	6650	(1/2+,3/2+,5/2+)		4386 (91)
51.6	20-CA-51	6820	(1/2+,3/2+,5/2+)		4386 (91)
51.6	20-CA-51	7450	(1/2+,3/2+,5/2+)		4386 (91)
51.6	20-CA-51	7910	(1/2+,3/2+,5/2+)		4386 (91)
52.5	20-CA-52	5570			4.69E3 (47)
52.5	20-CA-52	5800			4.69E3 (47)
52.5	20-CA-52	7010			4.69E3 (47)
52.5	20-CA-52	8210			4.69E3 (47)
52.5	20-CA-52	9190			4.69E3 (47)
136.7	52-TE-136	5160 (3)	(16,17-)		4.67E+3 (10)
137.9	54-XE-137	5025.1 (16)			4025.5 (3)
137.9	54-XE-137	5080.2 (13)	(+)		4025.5 (3)
137.9	54-XE-137	5125 (3)			4025.5 (3)
137.9	54-XE-137	5132.2 (20)			4025.5 (3)
137.9	54-XE-137	5148.8 (12)			4025.5 (3)
137.9	54-XE-137	5158.2 (16)	(+)		4025.5 (3)
137.9	54-XE-137	5170.2 (8)			4025.5 (3)

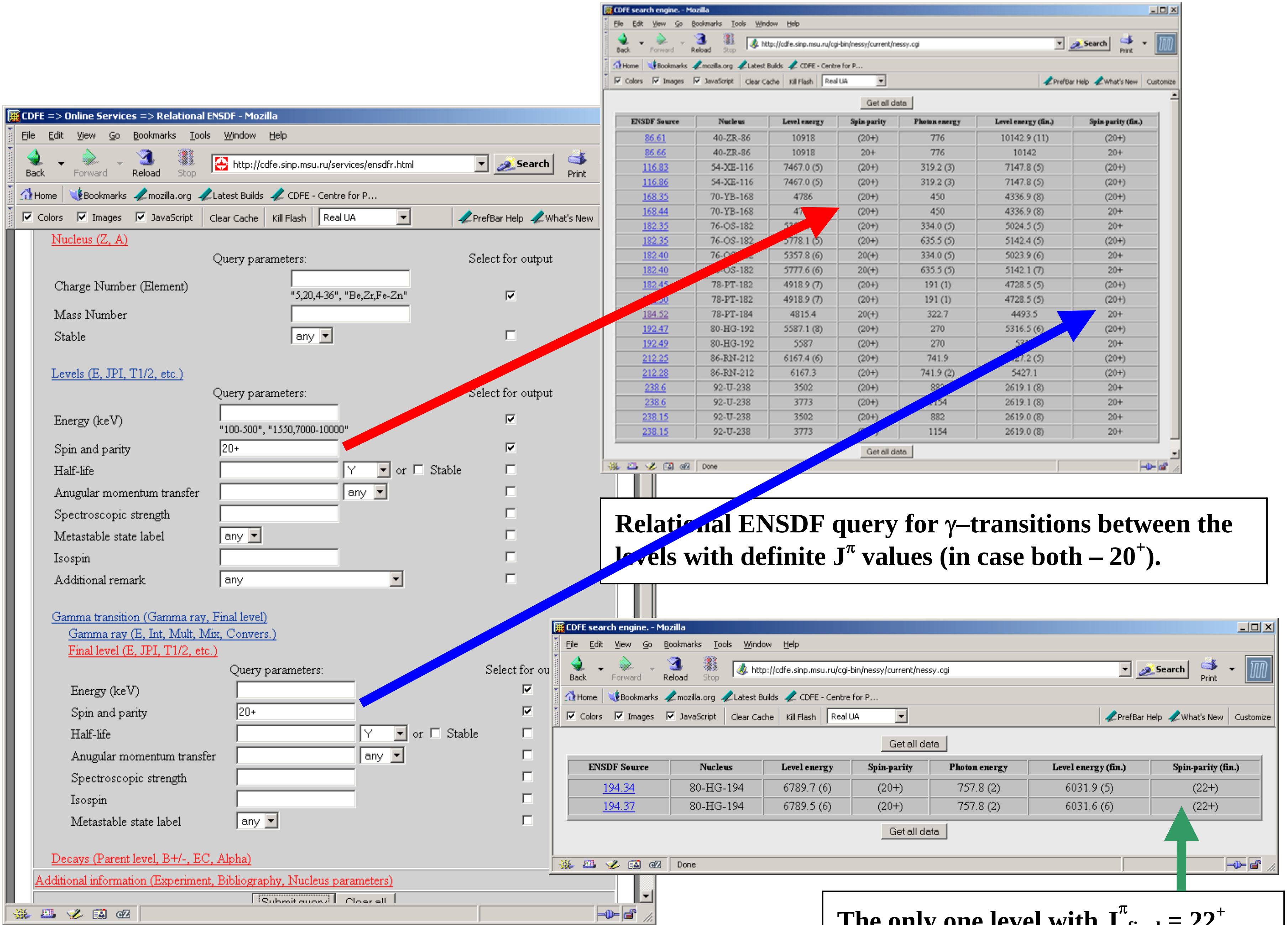
Relational ENSDF query for levels with energy more than neutron separation energy (requested also) in region 4 – 5 MeV.



ENSDF Source	Nucleus	Experiment information
41.19	18-AR-41	40AR(D,PG),2H(40AR,PG)
41.24	19-K-41	2H(40AR,NG)
41.61	20-CA-41	40CA(D,PG),2H(40CA,PG)
46.50	22-TI-46	12C(40CA,A2PG)
47.31	22-TI-47	10B(40CA,3PG), 36S(14C,3NG), 44CA(7LI,3NPG), 31P(19F,N2PG)
47.50	23-V-47	10B(40CA,N2PG),24MG(32S,2APG), 31P(19F,P2NG),40CA(10B,N2PG), 40CA(12C,PAG)
47.60	24-CR-47	10B(40CA,P2NG), 40CA(12C,NAG), 46TI(3HE,2NG)
48.78	24-CR-48	10B(40CA,PNG), 12C(40CA,2N2PG)
48.79	24-CR-48	12C(40CA,2N2PG), 10B(40CA,PNG)
48.86	25-MN-48	12C(40CA,3NP) E=456 MEV
49.45	23-V-49	12C(40CA,3PG), 24MG(32S,3PAG), 27AL(28SI,APNG), 40CA(12C,3PG)
49.58	24-CR-49	12C(40CA,N2PG),40CA(12C,N2PG), (14N,APG),27AL(28SI,APNG)
49.65	25-MN-49	12C(40CA,2NPG) E=160 MEV
49.68	26-FE-49	9BE(58NI,X), 40CA(12C,3N), W(40CA,X)
60.69	28-NI-60	60NI(40AR,40AR)
73.55	35-BR-73	40CA(40CA,A3PG)
73.59	36-KR-73	40CA(36AR,2PNG),(40CA,A2PNG)
75.61	37-RB-75	40CA(40CA,APG)
77.62	37-RB-77	40CA(40CA,3PG)
77.64	38-SR-77	40CA(40CA,2PNG)

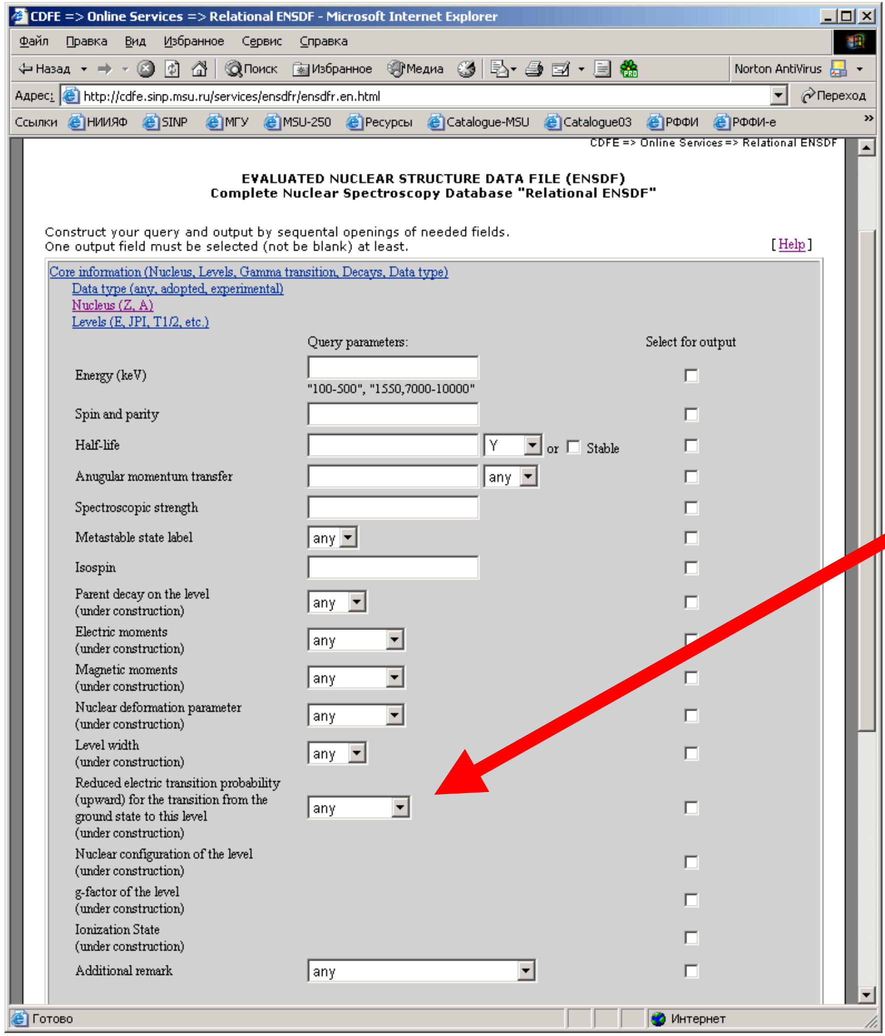
95.68	46-PD-95	58NI(40CA,N2P)
95.69	47-AG-95	58NI(40CA,P2N)
96.70	45-RH-96	64ZN(40CA,A3PNG)
96.74	46-PD-96	60NI(40CA,2P2NG)
97.75	46-PD-97	64ZN(40CA,A2PNG)
99.73	47-AG-99	64ZN(40CA,3P2NG)
126.55	58-CE-126	92MO(40CA,2PAG)
126.57	59-PR-126	92MO(40CA,APNG)
128.59	59-PR-128	94MO(40CA,APNG)
128.61	60-ND-128	92MO(40CA,2P2NG)
130.75	59-PR-130	94MO(40CA,3PNG)
130.82	60-ND-130	92MO(40CA,2PG),96RU(40CA,2PAG)
130.83	60-ND-130	94MO(40CA,2P2NG)
131.57	60-ND-131	94MO(40CA,2PNG)
132.59	62-SM-132	96RU(40CA,2P2NG)
133.56	61-PM-133	96RU(40CA,3PG) E=180 MEV
133.59	62-SM-133	96RU(40CA,2NPG)
133.60	62-SM-133	96RU(40CA,2PNG)
144.68	64-GD-144	108PD(40AR,4NG)
145.67	64-GD-145	110PD(40AR,5NG)
150.63	66-DY-150	114CD(40AR,4NG)
161.50	72-HF-161	126TE(40CA,5NG)
162.55	72-HF-162	126TE(40CA,4NG), 116SN(48TI,2NG)
180.48	78-PT-180	144ND(40AR,4NG)
181.41	78-PT-181	144ND(40AR,3NG)
181.50	80-HG-181	144SM(40AR,3NG)
192.64	82-PB-192	182W(16O,6NG), GD(40AR,XNG)
206.70	88-RA-206	170YB(40AR,4NG)

Relational ENSDF query for all reactions with incident A = 40 nuclides.



Relational ENSDF query for γ–transitions between the levels with definite J^π values (in case both – 20^+).

The only one level with $J^\pi_{final} = 22^+$.



Relational ENSDF Levels data search perspectives (new fields - under construction).